Lewis River Case Study Final Report

A decision-support tool for assessing watershed-scale habitat recovery strategies for ESA-listed salmonids

Appendix E: Surface Sediment, Erosion, and Runoff

May 2007

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Modeled Sediment and Runoff

We used a physically-based modeling approach to identify sediment sources and estimate sediment yield and runoff using GIS databases. Basin topography, soil type, and land-cover were the databases used in the models (described in Appendix A). Relative sediment and runoff production and impairment (low, moderate, high, none) were estimated based on the Water Erosion Prediction Procedure (WEPP) and the disturbed WEPP and WEPPROAD models (Flanagan and Livingston 1995; Elliot and Hall 1997; Elliot et al. 2000) as well as rules for landslide and road-erosion and runoff potential. The relative runoff change from historical to current conditions was based only on surface storm runoff. The impairment ratings were determined from the change in sediment yield and runoff between historical and current land cover conditions.

The primary objectives of the HU level analyses were to: 1) identify areas within subwatersheds which are more likely to deliver sediment and storm surface runoff to stream channels, 2) identify the relative contribution of three sediment sources—surface, mass wasting and road, delivered to streams, 3) provide a broad-scale context to reach-level sediment and hydrologic information and non-spatial historical stream hydrograph information, and 4) compare relative, qualitative differences between current and historical sediment and runoff levels to determine potentially impaired subwatersheds. In this appendix, we discuss field verification, sediment and runoff estimate corrections, and the tasks for developing estimates of sediment production and hydrologic runoff to be used in the Decision Support System (DSS). In addition to estimating sediment yield and runoff on the 7^{th} field HU scale, dominant flood discharge data and land cover modifiers were determined. This information is used in the Sediment Routing model (Appendix F).

Verification of Runoff and Sediment Screens

Field verification and additional data were collected during the 2003 summer. The objective of field verification was to evaluate the results of the 7^{th} field HU level sediment and runoff screens. We sampled 6 HUs to assess the assumptions used in the models (Figure E-1). The GIS datalayers examined for runoff were roads, soils, land cover, and DEM (slope). We visited the HUs noting evidence of surface runoff from hillslopes (e.g., gullies, slope rills/channels, headwater erosion, and material transported by overland flow) and roads. We also noted areas of groundwater emergence and erosion.

During field verification, we observed that in areas of ash-pumice soils, hillslope runoff and surface erosion responded differently than the general soil texture class (i.e., sand loam, silt loam, clay loam) attributed to these areas. Surface runoff and sediment transport were more common in these areas and were occurring in 10-20+ year old plantations (Figure E-2). Road runoff was more evident, including prism gullies on paved roads (Figure E-2). Field verification of modeled results indicated that another soil category, representing ash-pumice soils, was needed to improve surface and road sediment and runoff estimates. In addition, mass-wasting estimates needed revision. Based on these observations, the runoff and sediment yield rules for land cover, roads and mass wasting probability were modified to include a category for ash-pumice soil texture. The runoff and sediment yield values for these areas were changed and incorporated into the meta polygon level analysis (Appendix A). The WEPP models were used to estimate surface runoff and sediment yield for the ash conditions. Riparian buffer modifiers were incorporated into the analysis. Where present, the riparian modifiers lessened surface sediment and runoff delivery.

Sediment and runoff adjustments

Model Storm Runoff and Surface Erosion

Hydrologic runoff and surface sediment yield were estimated using two versions of the WEPP model: WEPP hillslope model (http://topsoil.nserl.purdue.edu/nserlweb/weppmain/) and US Forest Service Disturbed WEPP and WEPPROAD models (http://forest.moscowfsl.wsu.edu/fswepp/). The surface erosion and runoff data were adjusted by adding another soil class for ash-pumice soils. Runoff production from agricultural lands was estimated using the WEPP hillslope model a numerical distributed process-based model (Lane et al. 1989, Flanagan and Livingston 1995). This model calculates surface and shallow subsurface storm runoff, i.e., runoff from the rooting zone, and surface sediment yield. Surface erosion and storm runoff rates from forest, shrub, native grasslands, clear cuts, and fire were estimated using the Forest Service Disturbed WEPP model (Elliot and Hall 1997; Conner, et al. 2000; Elliot et al. 1995; Elliot et al. 2000).

Both models are mostly used for estimating sediment erosion and water availability on a single hillslope or small watershed scale. The lateral drainage wings meet the scale criteria for small watershed (e.g., Lane et al. 1997). WEPP simulates the conditions that impact erosion for every day in a multiple-year run based on the amount of vegetation canopy, the surface residue, and the soil water content. Variables used are vegetation type, vegetation management, cover, soil texture or series, slope and climate. For each day that has a precipitation event, WEPP determines whether the event is rain or snow, and calculates the infiltration and runoff based on local precipitation and storm patterns. When there is excess precipitation, WEPP routes the excess precipitation as surface runoff, calculating erosion or deposition rates for at least 100 points on the hillslope. It then calculates the average sediment yield and runoff from the hillslope. The U.S. Forest Service Disturbed WEPP model assumes two overland flow elements. Users can specify buffers below a skid trail, prescribed fire, or harvesting activity in forests.

The soil texture classes, slope classes and land cover used in the WEPP model are described in Appendix A, as well as Table E-1 and Table E-2. The models were used on multiple land cover scenarios, historical, current, and potential (13 landscapes). Based on the available information, the historical scenario is a forested watershed with interspersed meadows, wetlands, and other covers, and no large stand-replacing fires. Natural disturbances such as fire and volcanic activity can produce much more sediment than some management activities. However, there is not adequate information to incorporate these into the model with the exception of ash-pumice soils. No extensive natural stand-replacing fires were evident in the recent history (since the late 1700s). There have been extensive stand-replacing fires caused by human error and logging practices in the early to mid 1900s. Historical eruptions from Mt. St. Helens caused spot fires but most were of small extent (Agee 1993). The soils are assumed to be the same as for the current condition.

The USFS Disturbed WEPP model did not have an option for old growth so the 20-year forest category was used to represent mid-to-late seral stage. Although 20-year forests are not defined as hydrologically mature (WFPB 2000), WEPP runoff and sediment estimates approach background levels for this land cover. We assume for this analysis that sediment yield and surface storm runoff estimates in 20-year forests are in the same order of magnitude as data from old growth areas in similar geology and in the Pacific Northwest (Larsen and Sidle 1980, Reid and Dunne 1996, PWI 1998, PacificCorp and Cowlitz PUD 2002). Agricultural and rangeland areas were considered to have only one slope class, so sediment yield and runoff only varied by type of agriculture and not by topographic class. The agricultural model incorporates bare ground. Urban areas are treated separately. Zero sediment is assumed for rocky areas.

Mass Wasting and Road Erosion

Natural sediment production from mass wasting was estimated using landslide data from unmanaged HUs and landslide inventories in the Lewis watershed (PWI 1998, PacificCorp and Cowlitz PUD 2002). Management-related landslide sediment yield was extrapolated from existing landslide inventories. Field verification indicated that the 7th field HU assessment mass wasting estimates were inaccurate in areas of ash-pumice soils. Unlike surface runoff and erosion, mass wasting appeared to occur less often than predicted. New rules concerning presence or absence of ash-pumice soils were incorporated into the DNR mass wasting GIS model to better represent conditions on the ground. For ash-pumice soil, the percent slope was increased for each mass wasting probability class, e.g., for concave slopes the percent slope for high mass wasting probability was increased from 50% to 80%. New rules on land cover and road density were added to the decision support mass wasting model (Figure E-2).

In the HU level sediment screen, road erosion rates were calculated from rates previously estimated (PWI 1998, PacificCorp and Cowlitz PUD 2002) and modified by road surface and presence of stream adjacent roads. Road conditions in the upper watershed were extrapolated from the road survey done for the Upper East Fork (PWI 1998). The road survey was based on the protocol outlined in Washington Forest Practices Board Watershed Assessment Manual (1997).

Following field verification, road runoff and surface erosion models were refined from the HU estimates using the U.S. Forest Service programs WEPPROAD (Elliot et al. 1995, Elliot et al. 2000) and an ash-pumice soil class was added (Figure E-3). The road parameters were based on previous road surveys (PWI 1998) and road surveys conducted during 2003 field verification. Paved roads are assumed to contribute sediment from road fill slopes only. Based on estimates in the Washington Forest Practices Manual (WFPB 2000), fill slopes contribute 20% of unpaved road sediment. From road surveys, we adjusted this to 10% of unpaved road sediment for paved roads.

Distance and riparian modifiers were developed from WEPPROAD models (Figure E-3, Table E-3). Riparian buffer width was 33 meters for the analysis. These modifiers were used to attenuate both runoff and sediment delivery to streams as distance from road crossings and riparian buffers increased (Table E-3).

Sediment size distribution

The sediment routing model, described in Appendix F, used sediment size distributions. Sediment size distributions for surface and road sediment yields were obtained from the SSURGO databases and soil surveys for each county in Lewis basin (McGee 1972, Call 1974, Haggen 1990, NRCS 2004). In the database, each soil series (MUKEY in the database) has a distribution based on percent of size greater or less than a given sieve size. Soil information from the Natural Resource Conservation Service (NRCS) was not available on USFS lands. Sediment size data for similar soil series were extrapolated to the USFS soil database. Sediment sizes were distributed into 6 size classes (Table E-4). The SSURGO database does not provide information to estimate sediment sizes from mass wasting however. The sediment size distribution was estimated from mass wasting assessments from the Tilton and East Fork Lewis watershed as described in Appendix F.

Estimated 2.3-year flood discharge

We estimated the 2.3-year recurrence-interval flood discharge ($Q_{2.3}$) as an indicator of the mean annual flood and channel forming and bankfull flow (Black 1991, Whiting et al. 1999). Flood frequency and sediment transport analysis in the East Fork indicate that this flood is the average flood that initiates bedload transport (PWI, 1998). A sediment movement study done in Ole Creek indicates that the 2-2.5 year floods initiate bedload transport (PacificCorp and Cowlitz PUD 2002).

We used regression analyses to develop equations for estimating the 2.3-year flood discharge. The regression variables are 2.3-year flood measured at all USGS gauging stations in the Lewis watershed and drainage area above the gauges. In the East Fork Lewis River we had additional flood discharge information to develop a separate equation for that subwatershed. The best-fit equation for the $Q_{2.3}$ is a power function of drainage area:

> $Q_{2.3} = 4.235*A^{0.929}$, see=0.449, $r^2adj=0.90$ (from gages above Merwin reservoir)
>
> $Q_{2.3} = 4.4003*A^{0.9132}$, see=0.46, $r^2adj=0.91$ (for the upper East Fork Lewis)
>
> Where $Q_{2.3}$ is in ft^3/sec and drainage area A is in mi^2.

The average duration of the 2.3-year flood, 2.1 days, was estimated from the peak flow records from gauges in the Lewis River watershed. The duration and equations used in the sediment routing model are described in Appendix F. The 2.3-year flood discharge equations are used for the “unaltered case” describing hydrologic and hydraulic conditions in the watershed. Although the landscape had been disturbed before most gauges were established, we assume that over time the effects of disturbance on flood magnitude are attenuated. Land use, such as urbanization, conversion to agriculture, and timber harvest activities alter runoff processes over shorter time spans than the gauged periods of record in the Lewis River watershed (e.g., Booth and Jackson 1997, Jones and Grant 1996, Harr 1986). Analyses of temporal homogeneity showed no long-term trends in discharge data at gauges or in climatic data.

Land use modifiers (2.3-year flood)

An estimate of potential modification to the 2.3-year flood magnitude from land use activities is useful for providing information to the sediment routing model for evaluating the effect of restoration scenarios related to land management. The WEPP-generated runoff provides an indicator of changed conditions for only surface and shallow subsurface components (e.g., root zone) of stream runoff. However, surface storm runoff is only a small percentage (1-10%) of total stream runoff in forested watersheds in western Washington (Harr 1986, Dunne 1990). For example, the WEPP generated surface storm runoff contributions to total 2.3-year flood runoff were estimated to evaluate the reasonableness of the WEPP generated surface storm runoff contributions to total flood runoff (Table E-6). The results indicate that the WEPP generated runoff is less than 10% of the discharge. Consequently we needed an order of magnitude method to estimate increase in all storm related runoff (surface and subsurface) that does not require a precipitation-runoff model or generating hydrographs.

Three land use categories—forest harvest activities, agriculture, and urban, were used to estimate relative increases in 2.3-year floods from these activities. The modifiers developed were added to the DSS database. The estimates would be relevant for questions such as:

- If trees are grown in cluster x, what would be the relative decrease in 2.3-year flood, sediment transport, and potential spawning gravel scour in the associated reach, downstream reaches?
- If urban areas increase in cluster y by x%, what would be the relative increase in 2.3-year flood, sediment transport, and potential scour in the associated reach, downstream reaches?

Forest Harvest

Approximate increases in the 2.3-yr flood magnitudes for forested and roaded areas were estimated from storm precipitation, peak flow data, and stream runoff response to storms (e.g., Black 1991, Leopold and Dunne 1978):

$$Sr = \text{Storm runoff} / (\Sigma \text{ precipitation}_{to \ldots t5})$$

Where:

Sr is storm response

Storm runoff is in mm of water

Precipitation $_{to \ldots t5}$ is daily precipitation on the day of peak discharge ($_{to}$), back to 5 days preceding the peak ($_{t5}$).

The storm response index gives an indication of the response of a particular watershed to storm events. The higher the value, the more precipitation contributes to peak flow. The 5-day precipitation sum is from standard NRCS procedures on estimating storm volume (US Soil Conservation Service 1972). The storm response index is mostly associated with smaller flood events (<10-year flood). A similar analysis was originally done for the East

Fork at the Heisson gage (1927-1998 data) using precipitation data from Wind River climate station (PWI 1998).

Gauges in North Fork Lewis watersheds were evaluated for similar storm runoff response as found in the East Fork. Analyses of temporal and spatial homogeneity showed there was sufficient similarity in hydrologic patterns to use the data from East Fork to estimate the relative change to 2.3-year flood throughout the Lewis watershed.

The percent increases in flood discharge are storm response averages from known burn, road building, and road and harvest periods identified in the East Fork data (Table E-7). The increases include all storm runoff—surface and subsurface. The percent increases are similar to those found in other studies (e.g., Bowling and Lettenmeir 1997, Bowling and Lettenmeir 2001, Lewis et al. 2001).

Agricultural

The full WEPP model was designed to evaluate runoff, soil moisture conditions, and erosion on agricultural lands. This model addresses subsurface storm runoff more thoroughly than the Disturbed WEPP for forested areas. Accordingly we used the full WEPP model to estimate the relative increase in the 2.3-year flood for agricultural land uses. Two climate stations, Battleground and Packwood, were used in the analysis. The WEPP hillslope model was run for the 5 dominant soil series in the agricultural area in the Lewis and 3 agricultural covers—grass, row crop, and fallow. The soil series were grouped into 4 textural classes—silt, silt loam, sand loam, and clay loam. The modifiers are an average of the two climate stations and 3 agricultural covers classified by soil texture (Table E-8). The modifiers can be used for other grass conditions such as golf courses or play fields.

Urban

While “effective impervious area” (EIA) provides a measure of urban impact on streams, it does not provide a means to estimate potential increase in peak flow. We used data from a study conducted in the Puget Lowlands (Moscrip and Montgomery 1997) to develop the 2.3-year flood urban modifier. The modifier is a regression equation that equates percent of area in urban to a ratio of the 2.3-year flood post-urbanization to the 2.3 year flood pre-urbanization:

$$Q_{2.3post}/Q_{2.3pre} = 0.0298x+0.9255,\ see=0.264,\ r^2adj=0.73,$$

where x is the percent urban area.

The prediction results compare favorably to data from other studies (Dinocola 1989; Hollis 1975, Richey 1982). The equation shows that when percent urban is less than 2.5%, the modified $Q_{2.3}$ is less than the unmodified $Q_{2.3}$ (Table E-8). In these cases, the ratio between the two flows is assumed to be 1.0. Forcing the x-intercept to equal 1 (ratio equal to one is assumed to be the origin) provides similar results (Figure E-4). In effect using the equation as is will slightly underestimate (<1%) the discharge ratio for areas where % urban is less than 20% and slightly overestimate (<2%) where % urban is greater than 50%. Not forcing the regression model to go through 1 avoids difficulties resulting from forcing the model when it may not be appropriate. These results are not unlike the research on the effects of effective impervious area on peak flow (Booth and Jackson 1997, Hollis 1975). These studies indicate that when EIA is less than 3% than there is no impact on hydrologic conditions. Percent EIA is most often less than percent urban area.

Integration into the DSS

For running scenarios, values from modeled current conditions were permanently stored in lookup tables (Table E-1, Table E-2). To calculate surface sediment and hydrologic runoff in lateral drainage areas of individual segments, we summed area-weighted values from the lookup table for each land use category. Sediment input to streams was reduced by 45% on non-ash soils and by 38% on ash soils when riparian conditions were deemed to be functioning (Appendix H).

For running scenarios, values of road-derived sediment and runoff were calculated for the lateral drainage wings of each stream reach. Road sediment and runoff input to streams was reduced by functioning riparian conditions, as was surface sediment and runoff. Model parameters are detailed in Figure E-3. Values of mass wasting-derived sediment were calculated for the lateral drainage wing of each stream reach. Model parameters are detailed in Figure E-2.

The sediment models provided estimates of sediment yield by source to each drainage wing stream reach. The 2.3-year flood modifiers were also added to the DSS database. All output variables were then incorporated into the sediment routing model (see Appendix F).

Table E-1. WEPP estimates for sediment surface erosion (kg/m2/yr).

Vegetation	Soil Type	SlopeCode					
		≤10%	10-20%	20-30%	30-40%	40-50%	>50%
Clearcut	silt loam	0.008	0.020	0.033	0.045	0.055	0.068
Clearcut	clay loam	0.002	0.005	0.010	0.018	0.025	0.035
Clearcut	sand loam	0.000	0.002	0.005	0.010	0.011	0.015
Clearcut	ash, pumice subsoil	0.016	0.041	0.065	0.090	0.111	0.135
20_year	silt loam	0.002	0.005	0.010	0.012	0.015	0.020
20_year	clay loam	0.000	0.000	0.002	0.002	0.005	0.008
20_year	sand loam	0.000	0.000	0.000	0.002	0.002	0.002
20_year	ash, pumice subsoil	0.005	0.009	0.020	0.025	0.029	0.041
5_year	silt loam	0.008	0.020	0.033	0.045	0.055	0.068
5_year	clay loam	0.002	0.005	0.010	0.018	0.025	0.035
5_year	sand loam	0.000	0.002	0.005	0.010	0.011	0.015
5_year	ash, pumice subsoil	0.016	0.041	0.065	0.090	0.111	0.135
Shrubs	silt loam	0.000	0.002	0.010	0.025	0.030	0.037
Shrubs	clay loam	0.005	0.005	0.010	0.010	0.015	0.020
Shrubs	sand loam	0.000	0.000	0.000	0.000	0.000	0.002
Shrubs	ash, pumice subsoil	0.001	0.002	0.010	0.025	0.030	0.037
Grass	silt loam	0.055	0.132	0.198	0.253	0.294	0.328
Grass	clay loam	0.024	0.059	0.102	0.143	0.174	0.208
Grass	sand loam	0.002	0.010	0.027	0.043	0.058	0.071
Grass	ash, pumice subsoil	0.110	0.264	0.396	0.506	0.588	0.656
Urban_rock	silt loam	0.000	0.000	0.000	0.000	0.000	0.000
Urban_rock	clay loam	0.000	0.000	0.000	0.000	0.000	0.000
Urban_rock	sand loam	0.000	0.000	0.000	0.000	0.000	0.000
Urban_rock	ash, pumice subsoil	0.000	0.000	0.000	0.000	0.000	0.000
ag_alfalfa	silt loam	0.628	0	0	0	0	0
ag_alfalfa	clay loam	0.628	0	0	0	0	0
ag_alfalfa	sand loam	0.628	0	0	0	0	0
ag_alfalfa	ash, pumice subsoil	0.628	0	0	0	0	0
ag_row	silt loam	0.373	0	0	0	0	0
ag_row	clay loam	0.373	0	0	0	0	0
ag_row	sand loam	0.373	0	0	0	0	0
ag_row	ash, pumice subsoil	0.373	0	0	0	0	0
ag_recgrass	silt loam	0.201	0	0	0	0	0
ag_recgrass	clay loam	0.201	0	0	0	0	0
ag_recgrass	sand loam	0.201	0	0	0	0	0
ag_recgrass	ash, pumice subsoil	0.201	0	0	0	0	0

Table E-2. WEPP estimates for hydrologic surface runoff (mm of water/ yr/m2).

Vegetation	Soil Type	SlopeCode					
		≤10%	10-20%	20-30%	30-40%	40-50%	>50%
Clearcut	silt loam	100.584	100.584	100.076	100.076	100.076	100.584
Clearcut	clay loam	147.828	150.622	150.622	152.146	152.146	152.146
Clearcut	sand loam	42.164	43.434	43.434	43.434	43.434	43.434
Clearcut	ash, pumice subsoil	204.216	207.772	207.772	206.248	207.772	205.994
20_year	silt loam	6.35	5.842	6.096	6.35	6.604	6.604
20_year	clay loam	14.986	12.446	14.224	14.224	14.224	13.716
20_year	sand loam	2.286	2.286	2.286	2.286	2.286	2.286
20_year	ash, pumice subsoil	133.812	135.228	135.228	135.228	135.582	135.582
5_year	silt loam	9.906	10.668	10.668	10.668	10.668	10.922
5_year	clay loam	19.812	19.304	19.812	19.558	19.812	19.05
5_year	sand loam	2.794	2.794	3.048	3.048	3.048	3.048
5_year	ash, pumice subsoil	147.828	150.622	150.622	152.146	152.146	152.146
Shrubs	silt loam	0.508	1.778	4.064	6.604	6.858	6.604
Shrubs	clay loam	15.24	16.256	16.764	14.986	15.24	15.748
Shrubs	sand loam	0.508	1.016	1.27	1.778	1.778	1.778
Shrubs	ash, pumice subsoil	15.24	16.256	16.764	14.986	15.24	15.748
Grass	silt loam	22.098	22.606	22.606	22.606	22.352	22.352
Grass	clay loam	36.830	38.862	38.608	38.354	36.830	38.862
Grass	sand loam	6.096	6.858	7.112	7.366	7.366	7.366
Grass	ash, pumice subsoil	36.830	38.862	38.608	38.354	36.830	38.862
Urban_rock	silt loam	233.426	244.094	244.094	244.348	244.348	244.348
Urban_rock	clay loam	233.426	244.094	244.094	244.348	244.348	244.348
Urban_rock	sand loam	233.426	244.094	244.094	244.348	244.348	244.348
Urban_rock	ash, pumice subsoil	233.426	244.094	244.094	244.348	244.348	244.348
ag_alfalfa	silt loam	213.36	0	0	0	0	0
ag_alfalfa	clay loam	213.36	0	0	0	0	0
ag_alfalfa	sand loam	213.36	0	0	0	0	0
ag_alfalfa	ash, pumice subsoil	213.36	0	0	0	0	0
ag_row	silt loam	224.3667	0	0	0	0	0
ag_row	clay loam	224.3667	0	0	0	0	0
ag_row	sand loam	224.3667	0	0	0	0	0
ag_row	ash, pumice subsoil	224.3667	0	0	0	0	0
ag_recgrass	silt loam	191.3467	0	0	0	0	0
ag_recgrass	clay loam	191.3467	0	0	0	0	0
ag_recgrass	sand loam	191.3467	0	0	0	0	0
ag_recgrass	ash, pumice subsoil	191.3467	0	0	0	0	0

Table E-3. Sediment and runoff delivery modifiers are based on road distance from stream or stream crossing and riparian modifiers assuming a 33-meter buffer. Distance and riparian modifiers were developed from the WEPPROAD model.

Unpaved roads	Sediment			Runoff		
Road distance from stream or road crossing of stream (m)	Distance reduction	kg/m2/yr per unit of road prism	Riparian modifier	Distance reduction	mm/m2/yr per unit of road prism	Riparian modifier
Clay loam						
0-62		6.2	45%		0.86	62%
62-155	36%	2.21		23%	0.20	
155-248	19%	1.16		14%	0.12	
248-371	11%	0.70		9%	0.08	
371-495	8%	0.48		6%	0.05	
495-681	5%	0.30		5%	0.04	
>681	0%	0.00		0%	0.00	
Silt loam						
0-62		6.4	62%		0.69	32%
62-155	36%	2.30		22%	0.15	
155-248	19%	1.21		13%	0.09	
248-371	11%	0.73		9%	0.06	
371-495	8%	0.50		6%	0.04	
495-681	5%	0.35		4%	0.03	
>681	0%	0.00		4%	0.02	
Sand loam						
0-62		4.5	38%		0.38	72%
62-155	29%	1.32		24%	0.09	
155-248	15%	0.67		15%	0.06	
248-371	9%	0.39		9%	0.04	
371-495	6%	0.27		7%	0.03	
495-681	4%	0.19		4%	0.02	
>681	0%	0.00		0%	0.00	
Ash soils						
0-62		24.7	38%		0.9	9%
62-155	36%	8.78		36%	0.32	
155-248	19%	4.62		19%	0.17	
248-371	11%	2.78		11%	0.10	
371-495	8%	1.90		8%	0.07	
495-681	5%	1.20		5%	0.04	
>681	0%	0		0%	0	

Table E-4. Sediment size distributions (mm) for surface and road sediment yields were obtained from the SSURGO databases and soil surveys for each county in Lewis basin (NCRS gis database). In the database, each soil series (MUKEY in the database) has a distribution based on percent of size greater or less than a given sieve size. Sediment sizes were distributed into 6 size classes that were then incorporated into the DSS Access database

MUKEY	**> 78mm** (Cobble) GT78_PRC	**>4.8-78mm** (Coarse gravel) GT4.8_LT78	**1.0-4.8mm** (V. Coarse sand to gravel) LT4.8_GT1	**<1.0-0.5mm** (Coarse sand) LT1_GT.5	**<0.5-0.25mm** (Med sand) LT.5_GT.25	**<0.25mm** (Fine sand and less) LT.25_PRC
71952	0.0	28.0	2.5	3.6	5.0	60.9
71953	0.0	28.0	2.5	3.6	5.0	60.9
71954	2.7	22.7	10.0	12.4	11.7	40.5
71955	4.7	23.7	0.0	0.1	0.5	71.0
71956	0.0	0.0	0.1	0.4	1.0	98.5
71957	0.0	0.0	2.8	3.6	5.9	87.8
71958	0.0	0.0	2.8	3.6	5.9	87.8
71959	0.0	13.3	3.5	6.8	7.1	69.2
71960	0.0	13.3	3.5	6.8	7.1	69.2
71961	0.0	13.3	3.5	6.8	7.1	69.2
71962	0.0	13.3	3.5	6.8	7.1	69.2
71963	0.0	13.3	3.5	6.8	7.1	69.2
71964	0.0	13.3	4.2	6.1	6.4	69.9
71966	0.0	0.0	0.1	0.4	1.0	98.6
71967	1.7	38.3	2.2	3.0	4.2	50.6
71968	1.7	38.3	2.2	3.0	4.2	50.6
71969	1.7	38.3	2.2	3.0	4.2	50.6
71970	0.0	1.3	4.8	14.2	19.0	60.8

Table E-5. The WEPP generated surface storm runoff contributions were compared to total 2.3-year flood runoff to evaluate the reasonableness of the WEPP generated surface storm runoff contributions to total flood runoff. The results indicate that the WEPP generated runoff is less than 10% of the discharge.

Surface runoff as a % of the 2.3-year flood runoff				
Soils/land cover	Ash soils	Clay loam	Silt loam	Sand loam
Clearcut	2.3%	1.9%	2.2%	1.9%
5-year forest	2.2%	1.4%	1.95%	0.5%
20-year forest	1.9%	1.2%	1.6	0.5%

Table E-6. The percent increases in the 2.3-year flood discharge are storm response averages from known burn, road building, and road and harvest periods identified in the East Fork data. The harvest increase is the difference between harvest and roads and road categories. The increases include all storm runoff—surface and subsurface

Flood frequency	**% Increase in flood discharge**			
	Burn	Harvest	Road	Harvest & Roads
2.3 year	19%	8%	20%	28%

Table E-7. Data generated from the WEPP hillslope model was grouped in soil texture classes. Agricultural covers—grass, row crop, and fallow were averaged for Battleground and Packwood climate stations. The unadjusted 2.3-year flood is multiplied by the modifier to get new 2.3-year flood values.

Agricultural modifier for increasing 2.3-yr flood (Average)				
All soil types	Silt loam	Clay loam	Sand loam	Ash
1.65	1.36	1.12	2.34	N/A

Table E-8. Values of post-urban discharge for a given pre-urban discharges. Values are calculated using the regression equation for the ratio of post-urban 2.3-year flood discharge to pre-urban 2.3-year flood. The equation, based solely on data from Moscrip and Montgomery (1997), without the x-intercept forced to equal one is used. When percent urban area is less than 2.5 than the discharge ratio is less than 1. Since this is not a realistic case, we assume that for areas with less than 2.5% urban that the ratio is equal to 1.

% urban	Pre urban Discharge				
	100	**200**	**300**	**500**	**1000**
	Post Urban Discharge results				
2.45	99.9	199.7	299.6	499.3	998.6
10	122.4	244.8	367.1	611.9	1223.8
20	152.2	304.4	456.6	761.0	1522.1
30	182.0	364.1	546.1	910.2	1820.4
40	211.9	423.7	635.6	1059.4	2118.7
50	241.7	483.4	725.1	1208.5	2417.0
60	271.5	543.1	814.6	1357.7	2715.4
70	301.4	602.7	904.1	1506.8	3013.7
80	331.2	662.4	993.6	1656.0	3312.0
90	361.0	722.1	1083.1	1805.2	3610.3
100	390.9	781.7	1172.6	1954.3	3908.6

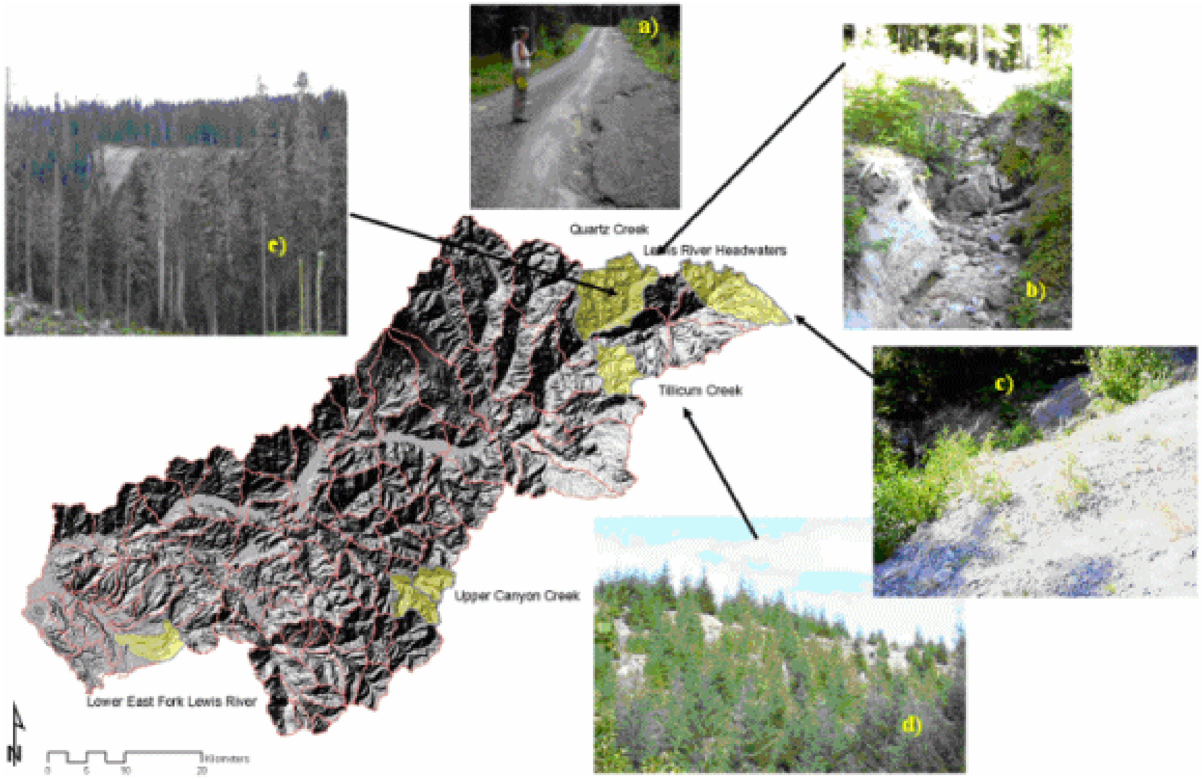

Figure E-1. Field verification watersheds are in yellow. Photo series show a) road erosion; b) runoff erosion in 20 year plantation; c) paved road prism erosion in ash-pumice area; d) continued surface erosion in 15+ year plantation in ash-pumice areas; e) surface slumping/erosion in clearcut in ash-pumice area.

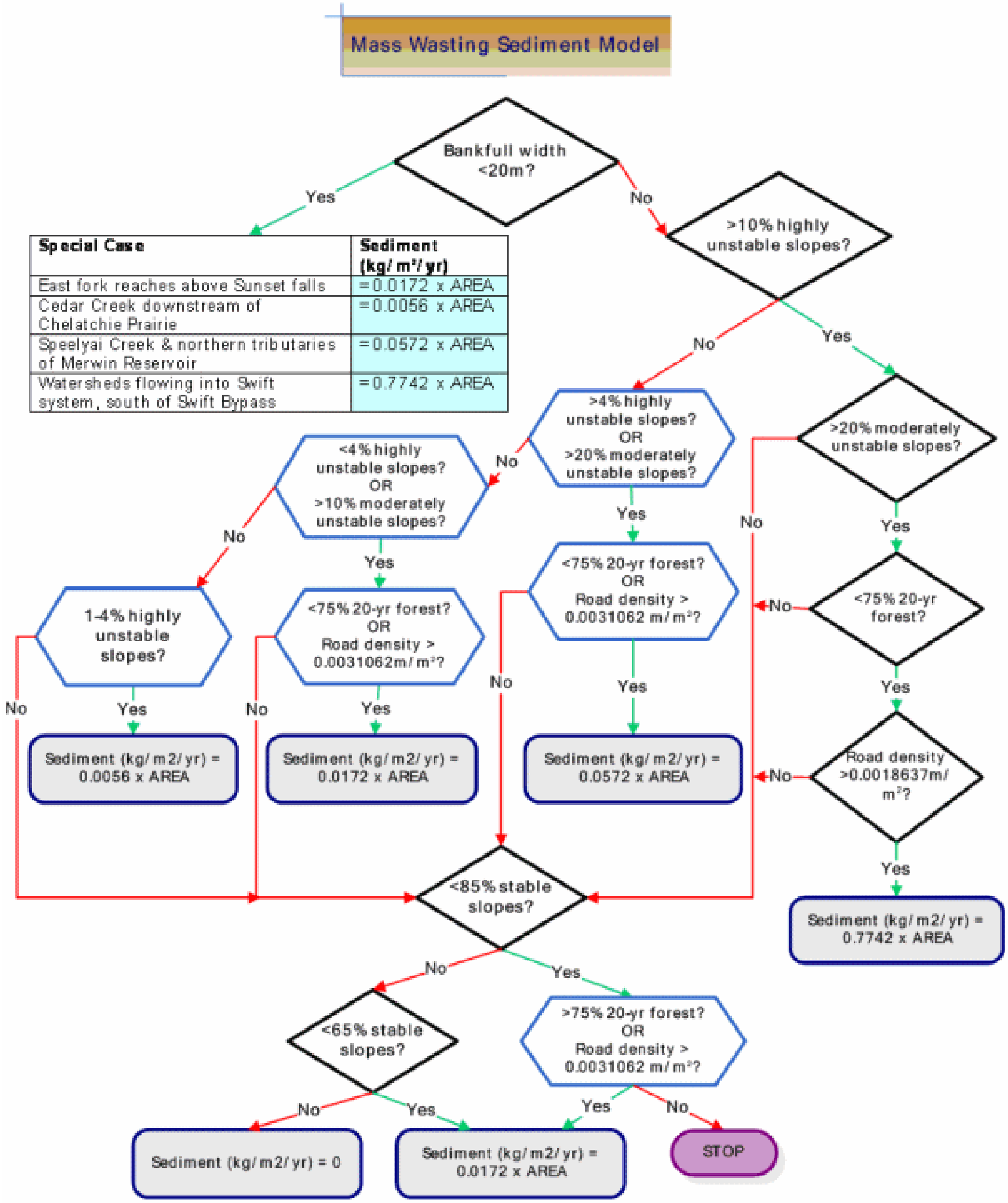

Figure E-2. The revised DSS mass wasting model after field verification incorporates changes in land cover and road density, and presence or absence of ash soils by increasing %slope values in the DNR mass wasting model. The DNR model provides the information on slope stability used in the DSS mass wasting model.

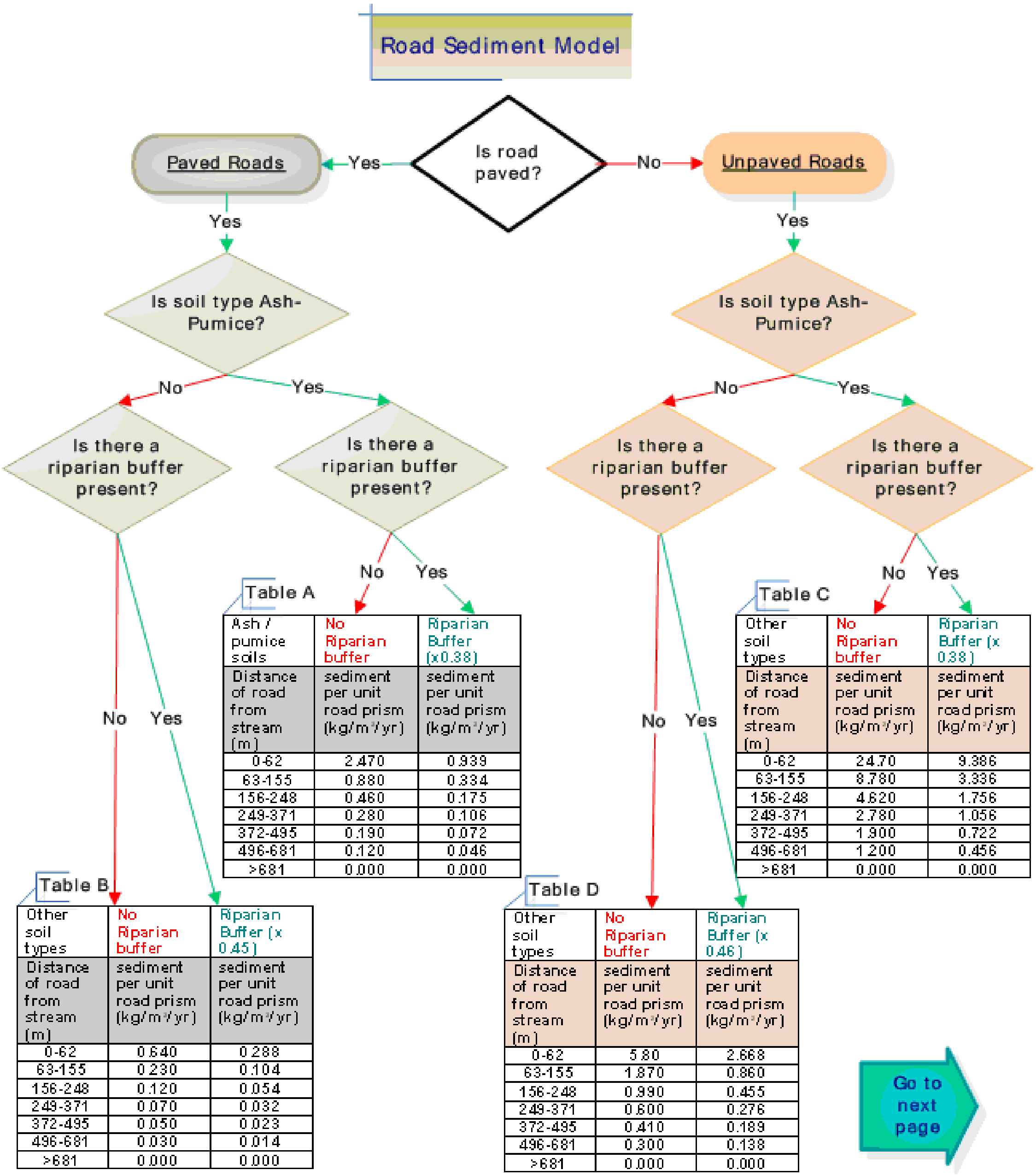

Table A

Ash / pumice soils	No Riparian buffer	Riparian Buffer (x0.38)
Distance of road from stream (m)	sediment per unit road prism ($kg/m^2/yr$)	sediment per unit road prism ($kg/m^2/yr$)
0-62	2.470	0.939
63-155	0.880	0.334
156-248	0.460	0.175
249-371	0.280	0.106
372-495	0.190	0.072
496-681	0.120	0.046
>681	0.000	0.000

Table B

Other soil types	No Riparian buffer	Riparian Buffer (x 0.45)
Distance of road from stream (m)	sediment per unit road prism ($kg/m^2/yr$)	sediment per unit road prism ($kg/m^2/yr$)
0-62	0.640	0.288
63-155	0.230	0.104
156-248	0.120	0.054
249-371	0.070	0.032
372-495	0.050	0.023
496-681	0.030	0.014
>681	0.000	0.000

Table C

Other soil types	No Riparian buffer	Riparian Buffer (x 0.38)
Distance of road from stream (m)	sediment per unit road prism ($kg/m^2/yr$)	sediment per unit road prism ($kg/m^2/yr$)
0-62	24.70	9.386
63-155	8.780	3.336
156-248	4.620	1.756
249-371	2.780	1.056
372-495	1.900	0.722
496-681	1.200	0.456
>681	0.000	0.000

Table D

Other soil types	No Riparian buffer	Riparian Buffer (x 0.46)
Distance of road from stream (m)	sediment per unit road prism ($kg/m^2/yr$)	sediment per unit road prism ($kg/m^2/yr$)
0-62	5.80	2.668
63-155	1.870	0.860
156-248	0.990	0.455
249-371	0.600	0.276
372-495	0.410	0.189
496-681	0.300	0.138
>681	0.000	0.000

Figure E-3. The revised Road Sediment model incorporates ash/pumice soils and distance from stream crossings. The model is applied for each road in the lateral drainage wings. The model decision tree is continued on the next page. The same model is used for runoff with the change in sediment table values to runoff table values.

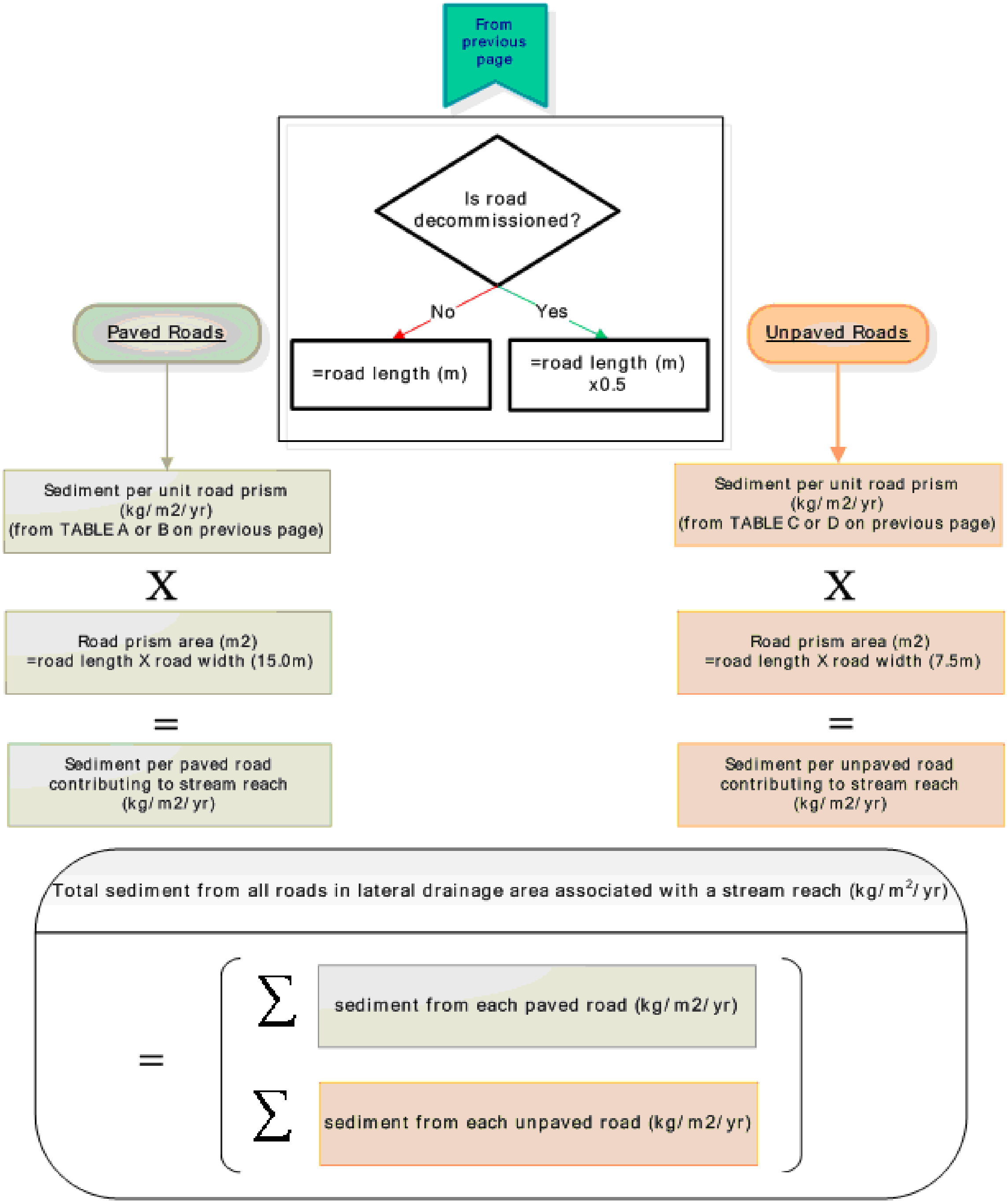

Figure E-3. (Continued): The revised Road Sediment model incorporates ash/pumice soils and distance from stream crossings. The model is applied for each road in the lateral drainage wings.

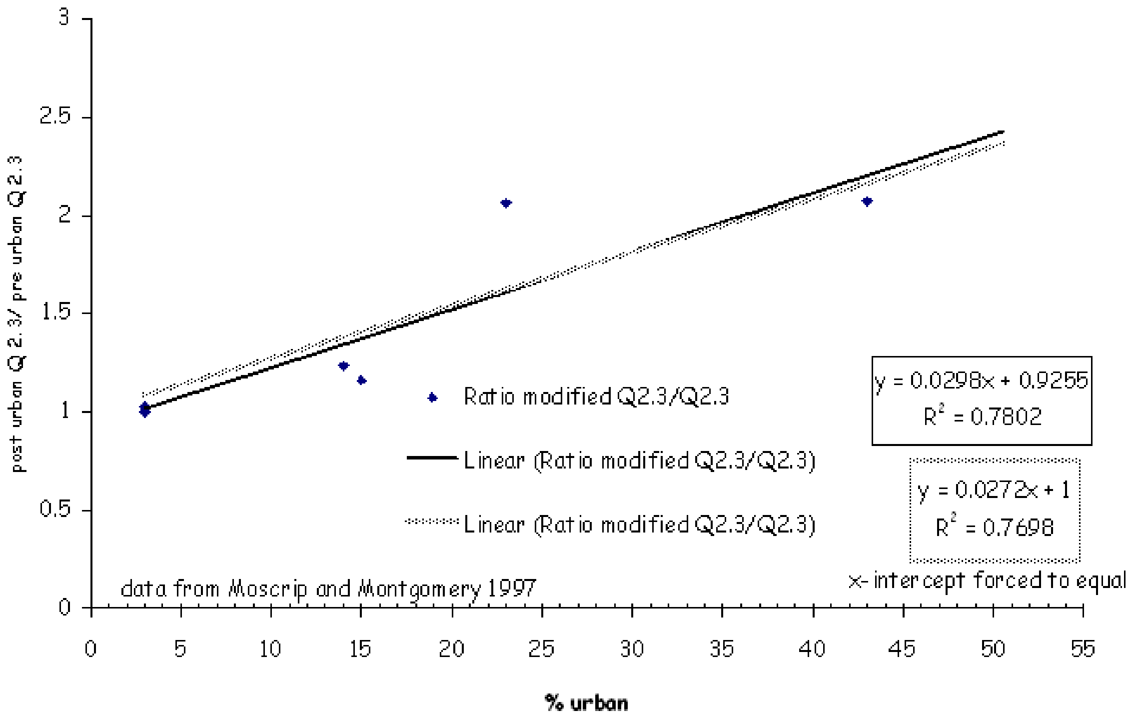

Figure E-4. Graph shows the relationship between the ratio of post urban 2.3-year flood to pre urban 2.3 year flood versus the percent area in urban. The regression equation, based solely on the data from Moscrip and Montgomery (1997), is the solid line. The dotted line and equation is the case where the x-intercept is forced to equal 1.

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